MOVPE-Grown Enhancement Mode HIGFET on 150 mm GaAs

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ABSTRACT

Enhancement mode HIGFETs have been grown by low pressure MOVPE on 150 mm diameter GaAs substrates using a single wafer MOVPE reactor. The MOVPE-grown HIGFET devices have rf performance exceeding the best HIGFET devices from commercially-available, MBE-grown epi.

INTRODUCTION

Enhancement mode HIGFETs (EMode) will be employed in integrated power amplifiers on next generation, high end cell phones with very long battery life. The devices will enable reduction of handset circuitry and offstate leakage (1,2). EMode devices are particularly suitable for applications requiring high saturated efficiency, such as GSM phones. Traditionally, in the implementation of complimentary GaAs, HIGFETs have been grown by MBE. Through the '90's, when the structure was grown by MOVPE, devices suffered poor reproducibility in dc parameters and high offstate leakage. Today, the difference between MBE and MOVPE material has reversed for n-channel EMode power devices.

EPITAXIAL GROWTH

The EMode epi structure grown by MOVPE consists of a semi-insulating 150mm GaAs substrate, GaAs/AlGaAs buffer, spacer of p- GaAs, silicon pulse doping, thin GaAs separator, InGaAs channel, AlGaAs gate insulator, and GaAs cap. The EMode epi was grown in a single wafer, low pressure MOVPE reactor described previously (3). The reagents were TMGa, TMAl, TMIn and arsine with disilane as the dopant source. Threshold voltage (Vth) for the HIGFETs is shown in Fig. 1 to be readily controlled with the grown-in charge. A pulse doping resulting in a Vth near 600 mV is chosen.. The GaAs/AlGaAs buffer is not present in MBE-grown material, this structure going directly from substrate to p- GaAs spacer. Wafers grown by MOVPE typically have a lower defect density than MBE-grown material resulting in higher processing yield.

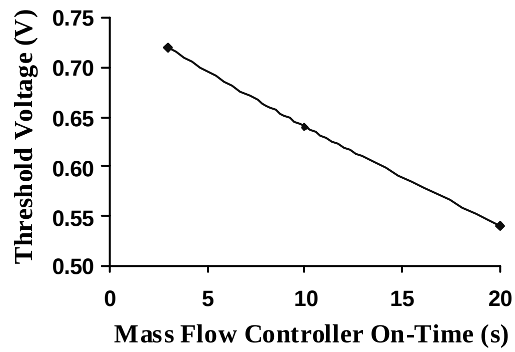

Fig.1. Threshold voltage versus doping time

Interface charge is well correlated with offstate leakage. MBE material achieves low leakage with no buffer directly from substrate oxide desorption in high vacuum. Desorption by itself is not effective with MOVPE growth. The successful growth of HIGFETs by MOVPE subjects the wafer surface to an insitu arsine soak at high temperature as well as incorporating a proprietary buffer structure. Atomic hydrogen from arsine decomposition converts many surface impurites into volatile species, for example, carbon or silicon to methanes or silanes. This combination of insitu clean and buffer can suppress the formation of substrate-epi interface charge and allows consistent device performance with low offstate leakage.

Interface charge can be removed with varying degrees of effectiveness, the choice of substrate vendor being an important variable In MOVPE, EMode devices fabricated on some vendor's substrates always have higher leakage than devices fabricated on other vendor's substrates. With some substrates, no insitu process or buffer can be found which eliminates interface charge. In addition, no insitu arsine soak process or buffer has been found which consistently eliminates interface charge on zero degree miscut substrates. For a vendor whose substrates give offstate leakage, good results have been obtained only on selected boules. A substrate vendor effect has also been seen in MBE HIGFET epi where a shift in threshold voltage occurs rather than increased leakage.

ELECTRICAL CHARACTERISTICS

The EMode HIGFET electrical characteristics are shown in Figs. 2-4. Fig. 2 is a comparison of the maximum available current (Imax) versus the growth method (MBE and MOVPE). Imax is measured at Vgs of 1.5 V and Vds of 1.5 V. The drain to gate breakdown for the two growth methods is shown in Fig. 3. The breakdown is measured at 1 mA/mm Igd.

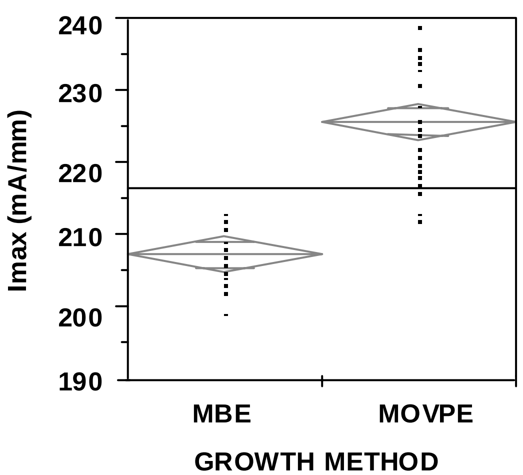

Fig. 2. Imax versus growth method.

Finally, the comparison of the offstate drain-source leakage (Idsoff) is shown in Fig. 4. Idsoff is measured at Vgs of 0 V and Vds of 3.5 V.

Pulsed IV measurements (4,5), illustrated in Figs. 5 and 6, show dispersion for MOVPE-grown and MBE-grown devices, respectively. These figures are plots of the drain to source current versus the drain to source voltage. The plots have two set of IV curves. The solid IV curves are dc measurements while the dotted curves are pulsed measurements. These curves are obtained from a 0.6 mm rf probeable device. The greater the delta between the dc and the pulsed IV curves, the higher the dispersion in the devices. The dispersion is quantified by calculating the ratio of the Ids value of the pulsed measurement vs. the Ids value of the dc measurement. The Ids value is picked at Vds equal to 1 V. From Figs. 5 and 6, the dispersion of the MOVPE-grown device is lower than that of MBE-grown devices (ratio of pulsed to dc of > 0.91 compared to <0.81). Pulse rise time is 0.3 microsecond at 1.2 V gate and 1.0 V source-drain bias.

Early in the development of the MOVPE EMode devices, high rf dispersion was seen for material having excellent dc parameters. Special attention was given to the processing of the GaAs cap layer, which resulted in very low dispersion for the MOVPE-grown devices. Subsequently, all epi was processed using the revised cap process and the comparison between MOVPE and MBE is for material processed to remove the component of dispersion associated with the surface.

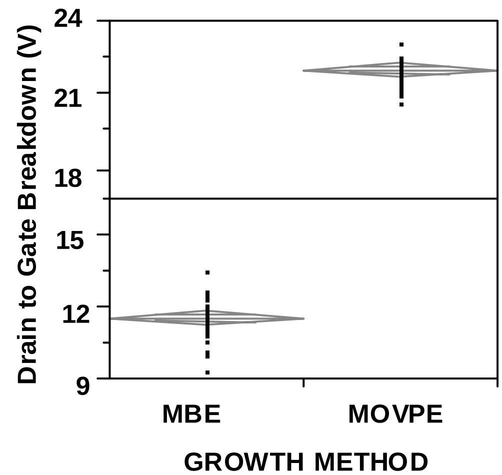

Fig. 3. Drain to gate breakdown versus growth method.

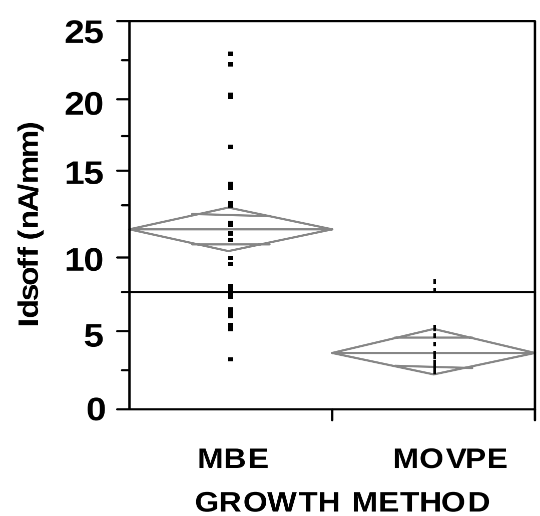

Fig. 4. Idsoff versus growth method.

Exceptions to a Generality become apparent as the sample size increases. Between the abstract and paper, a source of MBE-grown material with low dispersion (pulse ratio 0.90) was found. It appears likely that the preparation of the substrate is important in obtaining these results. A total of three MBE vendors have been evaluated. Also, a source of MOVPE material was sampled which has high dispersion. Three MOVPE vendors have been sampled, two yielding low dispersion epi. It may be stated that is has been easier to obtain material giving excellent rf performance from the MOVPE technique than from the MBE.

CONCLUSION

MOVPE epi in the enhancement mode HIGFET structure can be fabricated to meet or exceed power amplifier requirements for several next generation cell phones. MOVPE epi is the EMode material of choice for OEM customers. In fully implemented and packaged IPA modules, MOVPE-grown devices produce 1 dBm more power and 5% more power added efficiency than comparable MBE-grown devices.

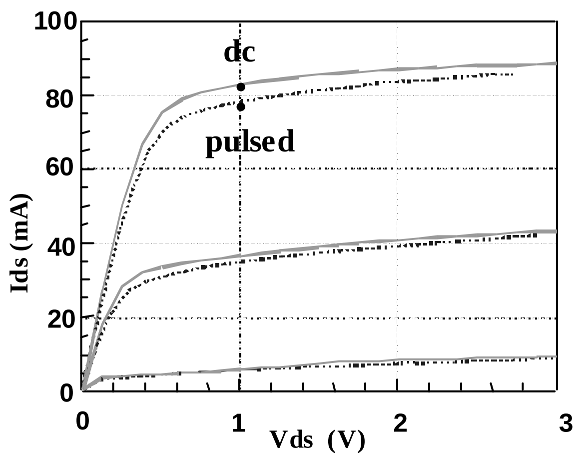

Fig. 5. dc versus pulsed IV for MOVPE (ratio 0.91)

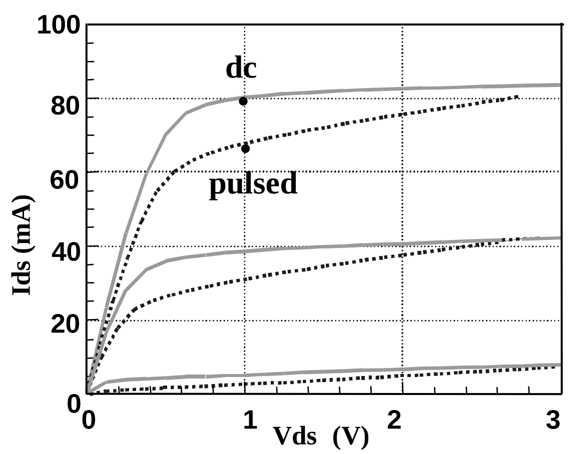

Fig. 6. dc versus pulsed IV for MBE (ratio 0.81)

ACKNOWLEDGMENTS

The contributions of Eric M. Johnson, Brian Cohn, Mikhail Mikhov, Matt Parker, Ken Dunham, Deborah Coombs, Jim Morzella, Larry Milman, Vic Borkenstein and Dave McKnight are greatly appreciated.

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